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Research article

Exploring the effects of climate change mitigation scenarios on timber, water, biodiversity and carbon values: A case study in Pozantı planning unit, Turkey

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ABSTRACT

This study evaluated the performance of three climate change mitigation management scenarios; business as usual (BAU), low intensity management (LIM) and high intensity management (HIM) to provide ecosystem services. ETCAP simulation model was used to forecast forest development for Pozantı area with 17,603 ha forests in Turkey. Wood production, biodiversity conservation, carbon sequestration and water provision were the primary ecosystem services. The species composition, natural composition, key habitats and understory vegetation are maintained and small forest openings were left intact for wildlife. Some forest areas were allowed to develop older to provide better opportunities of biodiversity conservation. The increase of carbon stock was related to age class shifts to older stages due mainly to increasing afforestation areas and productivity. The marginal differences in total carbon balance were related to a smaller increase in volume increment in BAU scenario and a higher allocation of harvest to energy production for the LIM and HIM scenarios. The planning scenarios allowed better production of water runoffs with slight differences among the output of management scenarios. The prevailing variable was the areas of afforestation. The impacts of a forest management scenario on ecosystem services highly depend on the development rate and intensity of management interventions.

1. Introduction

Forest management activities play an important role in mitigating climate change effects while providing various ecosystem goods and services such as water production, habitat for biodiversity and carbon sequestration. In this respect, multiple use planning provides a framework for accommodating various ecosystem goods and services (ES) and assessing the effects of management interventions on forest development to achieve management objectives. Forest ecosystems provide vital ES such as timber, water and soil protection, carbon sequestration, aesthetics and recreation and habitat for biodiversity (Kangas and Kangas, 2005; Eriksson and Hammer, 2006; Baskent et al., 2008; Pukkala, 2014; Borges et al., 2017). The dynamics of ecosystem characteristics influence the sustainable provision of these values determined by management interventions and natural disturbances (Keles and Baskent, 2007). Accommodating and understanding the dynamics and the tradeoffs among various multiple ES with a specific Decision Support System (DSS) is a great challenge in designing and implementing management interventions over time and space (Bettinger et al., 2007; Baskent et al., 2008; Nordström et al., 2011; Pukkala, 2014; Borges et al., 2017).

Over the last few decades, an increasing trend has been observed in accommodating various forest goods and services in forest management. There are several studies focusing on the integrated use of timber and other ES with the multipurpose forest management approach. In sustainable forest management, ecosystem services such as water provision (Vacik et al., 2001; Feller, 2005; Bettinger et al., 2007; Baskent and Kucuker, 2010; Keles and Baskent, 2011; Cademus et al., 2014), habitat for biodiversity (Eriksson and Hammer, 2006; Gustafsson and Perhans, 2010; Angelstam et al., 2011; Ezquerro et al., 2016; Felton et al., 2016; Löf et al., 2016; Lindbladh et al., 2017) and carbon sequestration (Backeus et al., 2006; Yousefpour and Hanewinkel, 2009; Cademus et al., 2014; Oliver et al., 2014; Pukkala, 2014; Dong et al., 2015; Yoshimoto et al., 2018) have been incorporated into forest management plans in addition to timber production. It has been pointed out that characterizing ecosystem services is as important as developing analytical tools such as DSS to forecast forest development with multiple management objectives and conservation targets (Von Gadow, 2004; Baskent et al., 2008; Eriksson et al., 2014).

Sustainable forest management provides an opportunity for incorporating carbon sequestration in an effort to manage climate changes. Increasing forest areas and growing stock, in addition to

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sustainable management, plays a major role in mitigating climate changes. In Turkey, Tolunay (2011) estimated the total forest carbon stock to be 2251.26 Tg C in 2004 with a net accumulation from 2.20 Tg C year^{-1} in 1990 to 6.82 Tg C year^{-1} in 2005. In the productive forests of Turkey, the carbon density in above- and below-ground biomass is 41.66 Mg C ha^{-1}, and this is slightly lower than that in the forests of Europe, which is 43.90 Mg ha^{-1} according to (UN-ECE/FAO, 2006). A higher proportion of afforestation now occurs on mineral soils and bare forest lands, while industrial plantations, although small, are gaining momentum to help boost the carbon sequestration capacities of forests. At large, Turkish forest policies focus on the control of illicit intervention, rehabilitation of degraded forests, increasing afforestation/reforestation activities, controlling natural disturbances, specifically wildfires and insects, and application of ecosystem based multiple use forest management principles (Anonymous, 2004; Baskent et al., 2008; Anonymous, 2010; Anonymous, 2015).

Biodiversity conservation has also been a primary planning concern in forest management planning. Similar to other jurisdictions, the biodiversity goal of Turkish forestry is to identify and protect target species and habitats and create unfragmented forest landscape structure (Anonymous, 2004). Prior to planning, forest management guidelines command the appropriate classification of a landscape for different forest use categories, including biodiversity and nature conservation areas, based on species composition and habitat configuration (Anonymous, 2008; Baskent et al., 2008; Johansson et al., 2013). Specifically, current forest legislation dictates protection of old growth forests, natural species composition, biodiversity hot spots, important plant and bird areas, riparian buffers, any protection areas identified by national and international conventions. These requirements are commonly used as proxy measures of habitat for biodiversity as it is quite hard and cumbersome to quantify it directly (Felton et al., 2016).

Water resources are both natural resources and public goods that play a critical role in a host of environmental processes and economic, social, and political activities (Forestry Commission, 2011). However, many of the natural processes and management activities occurring within a forest ecosystem influence water resources, but simply too complex, dynamic, and spatially variable to be precisely monitored and thoroughly understood (Hubbart et al., 2007). Thus, various indirect measures have been used to quantify and assess the flow of groundwater runoff over time (Bent, 2001; Bettinger et al., 2007; Maes et al., 2013). According to forest management guidelines, forests in Turkey are classified and managed, wherever possible, for water production and water protection objectives. The amount and the quality of water resources are highly dependent on the types of forest interventions and the characteristics of forest vegetation (i.e., species type, crown cover, density and the soil features) in addition to climate and topography (Anonymous, 2014). Management interventions are to be carefully designed and implemented particularly in stands that area classified under the “Nature Conservation and Erosion Control Management” units in a forest management plan based on the guidelines.

The scientific studies dealing with the integration of water, timber, carbon and habitat for biodiversity services have generally focused on the results based on a general level characterization of forest ecosystems to predict the interactions among forest ecosystem services (Vacik et al., 2001; Eriksson and Hammer, 2006; Gustafsson and Perhans, 2010; Angelstam et al., 2011; Ezquerro et al., 2016; Lindbladh et al., 2017). Very few simulation-based research initiatives have studied and presented the effects of various forest management strategies focusing on the mitigation of climate change effects on various forest ecosystem services (Bettinger et al., 2007; Keles and Baskent, 2011; Schwenk et al., 2012; Pukkala, 2014; Vacik et al., 2015; Alvarez-Miranda et al., 2018). By no doubt, forest management is seen as an effective tool to reduce carbon emission. Particularly, afforestation and rehabilitation activities embedded effectively into forest management planning are the primary treatments in mitigating the effects of climate change. However, there have been limited attempts to forecast the effects of climate change related management activities on the prevailing ecosystem goods and services such as timber production, carbon sequestration, habitat for biodiversity and water production (Dong et al., 2015; Nordström et al., 2016). Thus, developing management strategies focusing on climate change mitigation efforts and assessing their effects on various ecosystem services with a DSS is of a great challenge in integrated forest management planning endeavor.

The primary objective of the research described in this paper is to develop forest management scenarios accommodating various levels of management intensities and parameters, particularly different afforestation rates, using the ETÇAP DSS in the Pozantı forest planning unit. The secondary objective is to simulate and analyze the long-term effects of these management scenarios on some ecosystem services such as timber production, carbon sequestration, biodiversity and water production by examining and understanding forest dynamics.

2. Material and methods

2.1. ETÇAP model development

ETÇAP DSS has been developed as a stand-based, forest-level strategic planning model for assessing the effects of management interventions on forest dynamics and ecosystem values (Keleş, 2008; Keles and Baskent, 2007, 2011; Baskent and Kucuker, 2010; Baskent et al., 2014). Various ES such as timber production, carbon sequestration, soil erosion, non-wood forest products and water production and habitat for biodiversity have been integrated into the system as management objectives. It is a deterministic simulation based decision support tool with even-aged management method and a collection of components such as planning parameters, inventory data, actions (treatments) and outputs, wrapped around a management scenario. Data input includes stand based forest inventory data, empirical yield curves, spatial forest cover type maps, product assortments, economic revenues and costs, silvicultural regimes and management guidelines. The model uses various management policies (i.e., even flow, non-declining yield), treatment rules (i.e., oldest first, highest yield first) and activities (i.e., harvesting, planting and commercial thinning) with user defined rates and intervals. The actions denote the set of silvicultural interventions identified for each stand type and management guidelines applied for a forest as a whole. The output element of the DSS includes forest performance indicators to assess the spatio-temporal dynamics of forest ecosystems over time.

The stands are to be stratified, first of all, into different management units and analysis areas for similar silvicultural regimes and management objectives. Prescriptions can be applied on each stand or a group of homogeneous stands based on a user-defined criteria. The model focuses on the allocation of forest areas to management regimes for treatment and product outputs based on multiple objectives. Projections are conducted for a defined planning horizon (i.e., 100 years), divided into periods (5, 10, 15, etc.).

Management scenarios are the crucial actions necessary for projecting the forest inventory over time and space. A management scenario includes a planning horizon, planning period, harvesting method, a set of rules for ordering stands for treatment and a set of levels at which these actions are implemented (Keles and Baskent, 2007). The treatment rules are a key instrument in controlling the distribution of management actions. Harvest rules can be combined to control the harvest by queuing stands for harvest based on both stand condition and geographic arrangement. There are several treatment rules such as “oldest first”, “highest volume first” and “highest mortality loss first” available in ETÇAP DSS.

Forest development and response to management actions is forecasted on an iteration basis. All stands are subject to harvesting unless stratified under a conservation management unit. Harvested stands are assigned to the first age class and follow the development pattern of empirical yield tables. Unharvested stands are assumed to follow their

predecessor yield curve after breakup and reassigned to the first age class. Unless harvested, stands are assumed to terminate and regenerate naturally as soon as they reach the age of mortality defined by the user. In case of multiple objectives, one leads the projection and the others are the products of simulation unless all of them are combined with a single monetary value such as net present value (NPV). The harvesting process is repeated until the requested time horizon is reached or the target has been achieved.

2.2. The case study area

Forest management plans in Turkey are prepared and implemented on a forest planning unit (FPU). Each of the 1419 FPUs in Turkey is a unique geographic administrative unit with an independent forest management plan. The case study was conducted in the Pozantı FPU within the province of Adana in the Southeastern Plateau of Turkey. The study area covers 22,606 ha, of which 17,603 ha is forested (11,537 ha productive, 6066 ha unproductive). There are 2259 ha of bare forest land suitable for afforestation activities in addition to unproductive areas that are subject to afforestation. The area has seven primary tree species with two hardwood species such as oak (*Quercus* spp.) and walnut (*Juglans regia*) and five softwood species such as Anatolian pine (*Pinus nigra*), Red pine (*Pinus brutia*), fir (*Abies cilicica*), Cedar (*Cedrus libani*) and Junipers (*Junipers* spp.) (Anonymous, 2014). The elevation ranges from 850 m to 1200 m a.s.l. and the average slope is about 49%. The area is under typical Mediterranean drought climate conditions. Based on climate data, mean annual temperature and rainfall are about 13.5 °C and 45 mm, respectively (Anonymous, 2014). Thus, this area is selected as the necessary data was in place and up-to-date and it is a typical and representative planning unit among the ones across the Mediterranean region which is quite sensitive to climate changes over time (FAO and Plan Bleu, 2018).

According to current forest management guidelines and policy, the case study area or Pozantı forest planning unit was classified into 11 forest management units (aka working circles), each comprising various planning approaches, forest classification methods, different management objectives, product types and the silvicultural interventions. Wood production, biodiversity conservation, soil protection and the provision of ecotourism and recreation are the main forest management objectives and conservation targets. The forest management units are designed to accommodate various combinations of forest values with certain objectives and conservation targets. Any forest management activities are to be carefully designed and implemented on erosion sensitive areas, riparian buffers, recreation areas and other areas subject to conservation targets (Anonymous, 2014). With this case study, it is expected that long term projection under various climate change related scenarios would contribute to better understanding of forest dynamics and future design of management planning before it is realized.

2.3. Development of management scenarios

Three management scenarios were developed to analyze forest dynamics with four ecosystem services in focus; timber, water, biodiversity and carbon sequestration. Generally, the current type, level and the intensities of forest management activities as described in the management guidelines are followed with the differences indicated in Table 1. The forests of the Pozantı case study area (CSA) under three scenarios were projected over 100 years with ten 10-year periods using the ETÇAP simulation DSS (Keleş, 2008; Baskent et al., 2014). The current rotation periods were used across all three scenarios. Anthropogenic and natural disturbances such as wildfires and insects are assumed to be under control as there is a strict national forest policy to safeguard the forest ecosystems.

The current management planning approach employs the area control method to generate the regulated forest structure in each management unit with little leeway; overshadowing to test the long term effects of various options including multiple objectives and public demands over time. Specifically, the guidelines confine management actions into a single period with user defined allocation of stands, a solo wood production objective and a manual preparation of plans. These features restrict one to explore the effects of various types, rules, levels and intensities of actions on the achievement of multiple objectives including climate change over time. However, the hypothesis defined in the form of a problem in this study relates to fact that the effects of various management actions including climate mitigation efforts on forest dynamics are significant. Thus, it is necessary to elaborate various future opportunities with modeling exercise and test the hypothesis and adopt the future management actions accordingly before it is actually happened.

Compared to the current forest management guidelines in Turkey, this study focuses primarily on developing management strategies to test the consequences of various afforestation rates, treatment intensities and climate changes reflected by modified yield projections as they strongly affect the capacity of forest ecosystem. There are approximately 8325 ha of potential areas for afforestation including bare forest lands and degraded or sparsely covered stands. 2000 ha of the potential afforestation areas (nearly 25%) is targeted to be afforested in the business as usual (BAU) scenario, 4000 ha (nearly 50%) in low intensity management (LIM) and 8000 ha (nearly 100%) is planned to be afforested in the high intensity management (HIM) scenario over 100 years of simulation. Thus, different rates of afforestation have been applied to each of the management scenarios (Table 1). It is important to note that all bare forest lands and degraded or sparsely covered stands that are subject to afforestation action are targeted to be afforested in HIM scenario over time to be able to test the full potential of the case study area in mitigating climate change effects. Red pine, Anatolian pine and Cedar are the primary natural tree species of the region used in afforestation process in an effort to maintain natural biodiversity and persist to the low precipitation condition (45 mm/year). Nearly 50% of the afforested areas is planted with Red pine, 40% with Anatolian pine and 10% with Cedar.

Unless stated otherwise, the current management guidelines are followed in applying silvicultural treatments (harvesting and thinning) to the stands across all scenarios. All scenarios used the “oldest first” treatment rule in applying harvesting and thinning interventions and simulating forest development over time. Various rotation ages for harvesting and minimum ages for thinning were used based on species type, site condition and the objective of a management unit (i.e., longer rotation in conservation oriented management unit). Stands are determined to be available for thinning based on tree species, crown closure, site and development stages. All stands over 40% crown closure and not scheduled for harvesting (i.e., final cut) are potentially available for thinning. Furthermore, between the lower and upper treatment ages, the available stands are treated in each period over time with the specified level or intensity of treatment. Given that and the forest classification system, it was decided to implement the current treatment level in BAU scenario and intensive treatments in the LIM and HIM scenarios as indicated in Table 1. Specifically, among the potential stands for thinning, 14% of standing volume of each potential stand is determined to be harvested in BAU scenario, 21% in LIM and 34% in HIM. With this specification, more intensive thinning is applied both in LIM and HIM scenarios to test its likely effects on the ecosystem services in question.

It should be noted that accommodating temperature changes within a modeling system is a significant challenge due to the acquisition of long term data and establishment of complex relationships between temperature and forest development. As there was no long term climate change data available for the case study region and a model used in the ETCAP DSS, the current empirical yield data was modified to accommodate temperature changes over 100 years of simulation. However, the effect of climate change on growth was indirectly assessed by

Table 1
Three forest management scenarios accommodating various management plan characteristics.

	BAU	LIM	HIM
Climate mitigation level	• Least: reflects the current wood production trend of CSA	• Medium: Increased bioenergy demand (pellets, short rotation coppice)	• Strong: High efforts in carbon mitigation are seen as an increase in harvest levels
Climate change effects on yield	• Mean yield increase of 10% at +3.70 C temperature by 2100	• Mean yield increase of 7% at +2.50 C temperature by 2100	• Mean yield increase of 4% at +1.50 C temperature by 2100
Afforestation level	• Low: 2000 ha (25% of available stands) is afforested over time (200 ha/period)	• Medium: 4000 ha (50% of available stands) is afforested over time (400 ha/period)	• High: 8000 ha (almost 100% of available stands) is afforested over time (800 ha/period)
Treatment level	• Current/low: 12% of standing volume in economical forest and 6% of standing volume in other forest areas over time	• Medium: 20% of standing volume in economical forest and 12% of standing volume in other forest areas over time	• High: 40% of standing volume in economical forest and 20% of standing volume in other forest areas over time

employing presumptive estimates of forest growth gains arising from increased temperatures. For example, rise in temperature enhances tree growth depending on the species, location, and site conditions (Albert and Schmidt, 2010). Specifically, based on a study about the effects of climate change on forest growth in Portugal (Anonymous, 2013) that has the similar latitude and geo-climatic condition with the CSA, an average of 10% increase in yield was foreseen in the severe climate change scenario (+3.7 °C), 7% in LIM scenario (+2.5 °C) and 4% in HIM scenario (+1.5 °C). The scenarios are developed to vary in terms of climate mitigation efforts and the resulting climate change information based on modeling efforts using the GLOBIOM model (Forsell et al., 2016; URL 2, 2018). Specifically, stronger mitigation policies restrict climate change, increase the use of biomass for energy and increase forest harvests. The assumption is based on the inferences that increases in temperature could result in increased forest productivity, especially in areas where tree growth was previously constrained by low temperatures and short growing seasons and in areas where water is not a limiting factor (Subramanian, 2016; Hember et al., 2017). This case study area mostly accommodates such environmental conditions.

2.4. Timber production

The productivity of timber was estimated with an in-house growth and yield projection procedure inherent in the DSS. First, empirical yield tables developed for the commercial species in different site classes were used to estimate the per area timber productivity of future stands. In other words, any stands regenerated or thinned will follow the projections by the empirical yield tables. The current stands, however, will grow and develop according to the relative growth adjustment procedure. Specifically, the growth of a current stand will follow a relative trend determined by the relationships between the actual growth based on timber inventory data and the development pattern of the empirical yield table. Therefore, the DSS provides all stand level data such as volume, basal area, increment and number of stems forecasted over time.

2.5. Carbon sequestration

The forest management modeling scenarios included the climate change impact on forest carbon stock changes. Carbon pools used in the DSS are i) above and below-ground biomass, ii) deadwood and ii) harvested wood products (HWP). Since there were no proper data and a model, the carbon in other pools such as litterfall and soil was not included. In calculating the C sequestration, a gain and loss approach is used as it is much easier. The gains are estimated as the above and below-ground biomass growth using IPCC guidelines of the country (i.e., Biomass Expansion Factor (BEF), volume increment and C factor) (URL 1, 2006; IPCC, 2006). The country specific BEFs related to the major forest types (i.e., softwood and hardwood) were used from the literature (Baskent and Keles, 2009; Tolunay, 2011). Biomass losses were derived from volumes removed during final and intermediate harvesting operations and mortality losses determined by the empirical yield curve. Furthermore, transfer of C from biomass gains to harvest and deadwood pools is also considered in the C sequestration. Deadwood (DW) was estimated using the carbon flow model (Bond-Lamberty and Gover, 2008) based on forest inventory projection data generated by ETCAP DSS. DW carbon stocks comprise of dead logs, roots and stumps categories which accumulate and decompose at different rates over time. Carbon emissions from various forest timber assortments such as sawlog and pulpwood were also taken into consideration and estimated in this study based on the lifetime of each wood product for each stand (50 years for saw logs, 40 years for mining pole, 15 years for boards, and a period for firewood, bark and harvest residues) (Baskent et al., 2008; Baskent and Keles, 2009; Black and Gallagher, 2010; Lippke et al., 2011). The decomposition rates of various wood assortments were computed by the exponential discard function proposed by Masera et al. (2003).

Carbon sequestration in HWP occurs in the storage of C in wood products from harvesting and from the added potential of energy substitution of energy demanding products such as steel or cement or fossil fuel energy production. (Sathre and O'Connor et al., 2010; Oliver et al., 2014). The modeling scenarios treated the inflows of HWP and allocation between HWP storage, energy or product substitution differently (Skog, 2008; Smyth et al., 2016). Table 2 shows the different assumptions for HWP product allocation applied to the three scenarios. It is assumed that there is a higher allocation of saw logs and pulp to energy substitution and similar higher allocation of saw logs to wood based panels (WBP) in the LIM and HIM scenarios, when compared to the BAU scenario. It is also assumed that 30% and 40% of harvest residues are used for energy under the LIM and HIM scenarios, respectively (Table 2).

2.6. Water production

Water yield, flood protection, water flow maintenance, erosion control and chemical condition are all water related ecosystem services (Maes et al., 2013). Ideally, the indicators used to quantify water services are annual runoff, annual quick and base flow, annual sediment loss and total nutrient export. Actually, however, some practical parameters such as (i) % of soil covered by shrubs and litter, % of removal of crop (harvesting) and species composition to measure the water yield and water flow maintenance and (ii) road density, harvesting (% of

Table 2
HWP allocations for the management scenarios.

	HWP fraction for each scenario		
Allocation	BAU	LIM	HIM
Saw logs to WBP	0.1	0.2	0.3
Saw logs to energy	0.1	0.2	0.3
Pulpwood to WBP	0.1	0.2	0.3
Pulpwood to energy	0.1	0.25	0.3
Harvest residue to energy	0.2	0.3	0.4

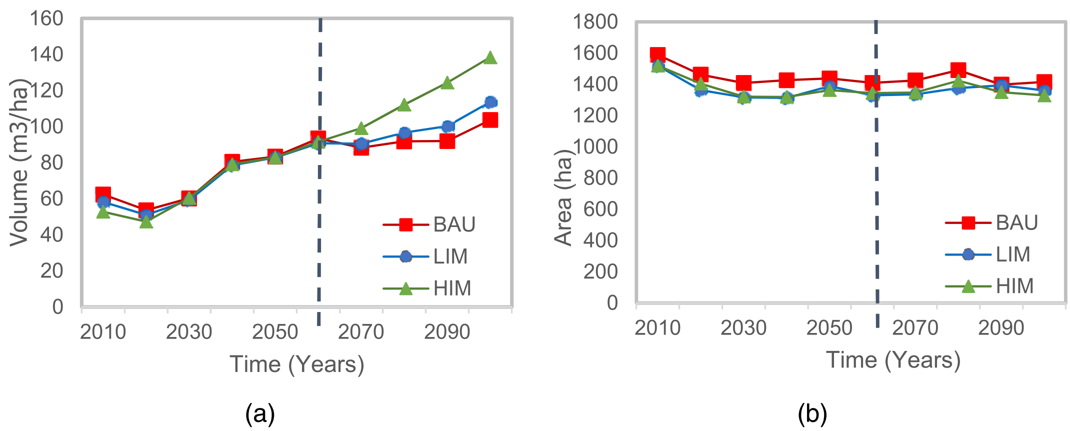

Fig. 1. The development of total standing volume (left) and final harvesting area (right) over 100 years.

removal), intensive grazing, fraction of soil covered by vegetation, burning (% of area affected) are used to measure water services (Maes et al., 2013). Water yield, an important component, is generally estimated based on its relationship to some stand parameters such as tree species mix, crown closure, basal area, mean stand diameter, number of stems, standing timber volume and leaf area index of trees. Among these, basal area has been used as a fairly good driving parameter in determining the amount of ground water produced in forest ecosystems (Tecle et al., 1998; Kucuker and Baskent, 2010; Keles and Baskent, 2011).

The water yield model developed by Mumcu (2007) and used by Kucuker and Baskent (2010) for similar yet different forest ecosystems indicated a fairly good relationship and was used in this study [1]. Mumcu (2007) took several soil samples and calculated soil water holding capacity based on water tables generated for different soil series using Thorntwaite method. Then, the soil type and water holding capacity were used as important parameters to incorporate the permeability of main bedrock. Evaporation and annual precipitation estimated based on the Thorntwaite tables were used to calculate the per area amount of water running off the surface in a forest ecosystem as follows;

$$WP = 1797.97 * e^{-0.0196*BA} \ (R^2{:}0.50,\ SE{:}\ 0.19) \quad (1)$$

where, WP: annual water production (ton/ha), BA: residual stand basal area (m^2/ha), and e:2.71828.

Water quality may be indirectly assessed with three main components: harvested areas, rotation length, chemical conditions. Increased harvest removal rates cause increases in nutrient leaking and decreases in nutrient uptake by plants, resulting in deteriorated water quality (Feller, 2005). Concentration of most nutrients in aquatic ecosystems decreases down to a minimum for mature forests, and then increases up to an equilibrium for old-growth forests (Buttle, 2011) as far as development stage is concerned.

2.7. Biodiversity conservation

Biodiversity services can be assessed with key habitat proxies or key determinants of habitat availability in relation to the biodiversity goal. These include, forest structures such as older larger trees, coarse woody debris, high stumps, species composition such as broadleaf tree species, native tree species, tree species diversity and disturbance regimes such as consistency with natural disturbance and proportion of older forest (Felton et al., 2016). Management regulations in Turkey state that older trees and the availability of different categories of dead wood in production forestry stands should increase. Silvicultural regulations promote the maintenance of small openings and individual mixed broadleaved trees for supporting biodiversity. At broader landscape scales, management guidelines also specify the need to increase the proportion of older forest, limit the area of landscapes clear-cut at a given point in time, and promote disturbance regimes which are more similar to the spatial and temporal scales of natural disturbances (Felton et al., 2016). Specifically, disturbance levels, native species mix, rate of broadleaved species, amount and size of deadwood, mean stand age, tree size, areas set aside for conservation, vertical sand structure defined by the volume of trees categorized by size classes and spatial configuration of stands defined by some fragmentation metrics are used to measure biodiversity services indirectly.

3. Results

3.1. Assessment of scenarios in relation to biodiversity implications

Generally, the scenarios considered indicate a landscape dramatically driven by an increase in standing volume, with the vast majority of this increase in primary commercial species of Calabrian pine, Anatolian pine and Taurus cedar. Almost all scenarios involve nearly a 100% increase in standing volume overall (60 m^3/ha base and 103–139 m^3/ha in 100 years) (Fig. 1). The general increase in standing volume is mostly associated with the renewal activities (new stands are assumed to grow according to the empirical yield tables) and afforestation of degraded stands with the primary species. In fact, afforestation of forest openings (i.e., 200ha in BAU, 400ha in LIM and 800 ha in HIM over 100 years) is the primary cause of volume increase. Regardless of the scenario, however, the contribution of all other non-commercial species are strongly encouraged and even dictated by the forest management and silvicultural regulations to be part of the floral composition of vascular plants to support biodiversity conservation in Turkey (Anonymous, 2008). It was noted that the scale of disturbance essentially remains the same (maximum 10% is allowed) throughout the scenarios and time periods considered (Fig. 1).

Importantly, the simulation indicates that the mix of tree species is becoming minimal by the end of the century, calling for an urgent attention to maintain the natural species composition. This outcome is inconsistent with biodiversity goals for the country. As the natural renewal of Junipers is quite slow and sometimes becomes very hard, the common pioneer tree species override the tree composition on the natural disturbance areas unless some active precautions are taken in time. Planting of such species in their natural areas seems to be necessary to maintain the natural stand composition of the region.

The two broadleaf tree species, walnut and oak, are projected to experience slight increases for the time period considered for all scenarios. While there are other broadleaf species such as hornbeam in this region, they do not appear in the inventory projection system. According to the forest management guidelines, tree species contribution to the species composition less than 10% is not shown in the inventory projection system, while they appear in the current database

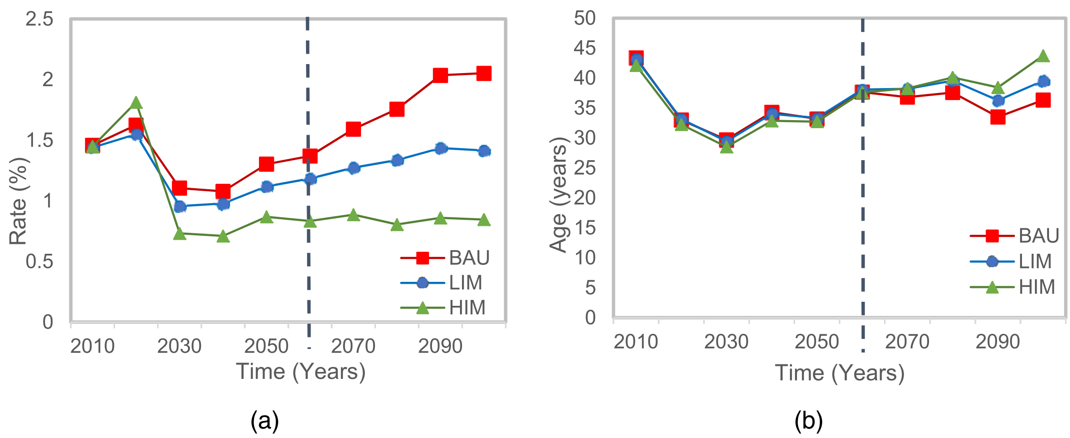

Fig. 2. The share of broadleaved species (left) and the mean stand age (right) over 100 years.

(Anonymous, 2008). As part of biodiversity conservation goals, however, the removal of such species from the stand composition during forest management activities is strictly forbidden. The natural share of such tree species and shrubs are encouraged to appear at least at the current level, while the rate of broadleaves within the total forest compassion is quite low (Fig. 2). Such a policy is expected to improve the circumstances for generalist broadleaf associated taxa, contributing to the status of biodiversity in general.

In terms of forest development stages, one of the key habitat indicators, the average age of the case study forest improves the biodiversity conservation status. For example, mean stand age appears to increase from just over 30 years, to between 30 and 45 years of age, depending on the scenario considered (Fig. 2). While there was a slight decrease by 30 years, as the old stands are harvested first, older development stages started to increase by the end of century as regenerated areas and afforested areas improved conditions later in the simulation. This outcome is consistent with the key goal of increasing forest age, though the greatest benefit to biodiversity is the net effect of the older age classes.

While the increase in average stand age is well reflected in the volume of large trees in the early half of the simulation (by 60), it is not well reflected afterwards (Fig. 3). Surprisingly, the early sharp decrease in the availability of large size classes of deadwood is related to the quick harvesting of larger trees before deadwood volume happens. After 30 years, the change of deadwood volume is quite stable (Fig. 3). The decrease of volume in larger trees and the stabilization of larger deadwood volume are once again derived from the forest management approach (regulated forest) that does not allow forest ecosystems to reach the equilibrium where larger trees and the associated deadwood volume occur within the landscape.

In short, the management scenarios applied to the Pozantı forest planning unit indicated relatively consistent trends, yet large increases in standing volume of the three primary forest trees; Calabrian pine, Anatolian pine and Taurus cedar. As a smaller proportion of the annual increment is harvested, the mean stand age gradually increases, with concomitant improvements to the size of standing trees in the early years, yet decreases in the deadwood provided.

3.2. *Assessment of management scenarios in relation to water production*

Generally speaking, diversification of stand age classes, maintaining current species composition, and careful classification of areas for various forest management objectives and conservation targets provide opportunities to create forest ecosystems more resistant to climate changes (Anonymous, 2013; Subramanian, 2016; Daniel et al., 2017). It is fortunate that forested areas increase gradually (Fig. 4) and the age class structure shifts a bit to the right (Fig. 5) allowing better production of fresh water. There are, however, some concerns about the rehabilitation of large degraded forests with climate resistant and adopted native species, main tree species replacing understory vegetation (Fig. 4) and risk management against wildfires in the area consisting primarily of fire prone Calabrian pine.

Fig. 6 shows the temporal dynamics of both basal area and the amount of ground water. The harvested areas and the level of harvest did not significantly change over time (Fig. 1). However, the amount of ground water continuously decreased for all three strategies with a slight exception in BAU scenario after 2050 due to leveling off of basal area. This is, by no means, related to the gradual increase of basal area due to afforestation and quick recovery of underproductive stands developing according to the empirical yield tables. The differences are

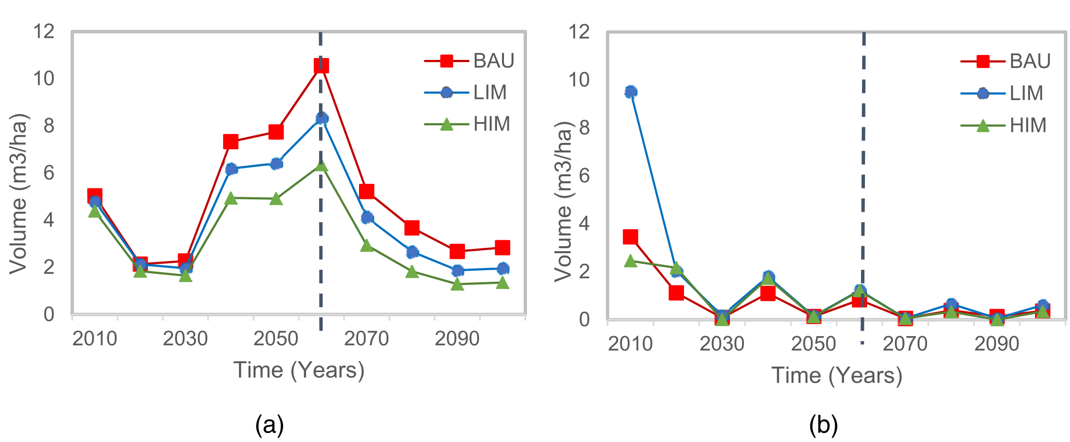

Fig. 3. Largest tree volume over 40 cm dbh (left) and the deadwood over 30 cm dbh (right) over 100 years.

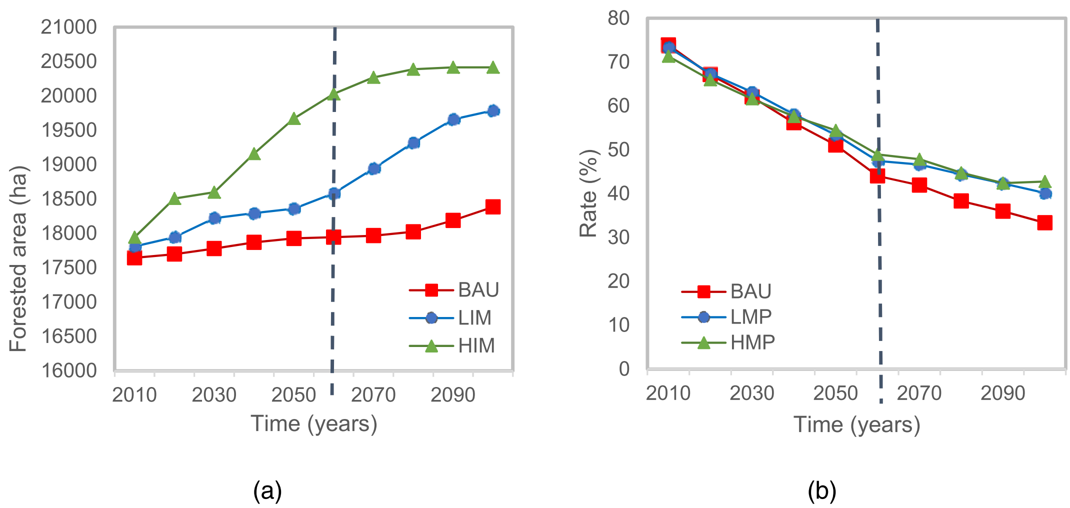

Fig. 4. Temporal evolution of forest area (left) and the rate of understory (right) over 100 years.

more pronounced in both the LIM and HIM scenarios compared to the BAU scenario. The outcome is related to the increasing rates of both afforestation and intensive thinning. The production of ground water is also related to the harvesting level, yet all strategies used the relatively constant harvesting level.

When indirect scoring of water quality is done using harvested areas, rotation length and chemical conditions, the results as an evolution of water quality can be seen as in Table 3. There were no chemicals applied to the area. Thus, the general evaluation is significantly improved by the forest management settings in three strategies. However, the simulated forests in LIM and HIM scenarios are better as more areas are afforested over time than that under BAU scenario. This trend is comparable to the qualitative assessment explained above.

3.3. Assessment of management scenarios in relation to C sequestration performance

The development of forest carbon stock shows no consistent changes over 100 years of simulation for all scenarios (Fig. 7). It is also apparent that C balance is almost neutral after 2080 in BAU. However, there is an apparent increasing trend, although smaller, in LIM and HIM scenarios compared to the BAU scenario. This appears to be associated strongly with a consistent increase in volume (from 30 m^3/ha to 140 m^3/ha) and volume increment (1.5 m^3/ha/year to 4.5 m^3/ha/year) over the

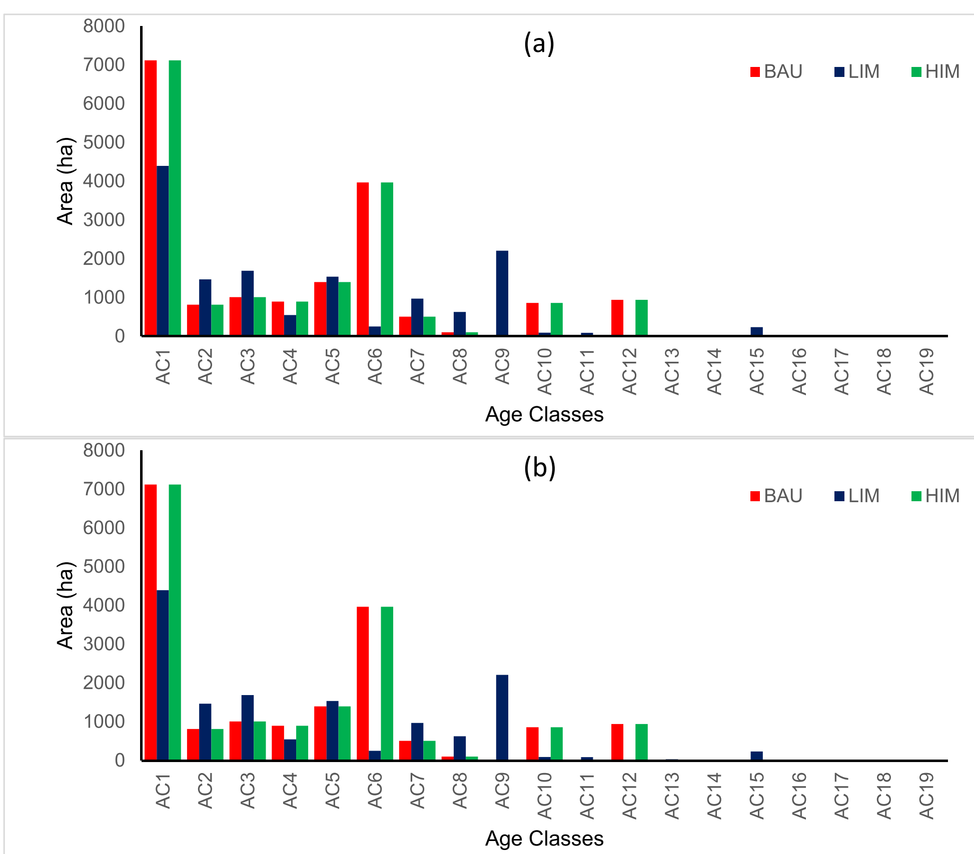

Fig. 5. Shifts in age class distribution, initial (left) and final (right), under three scenarios over 100 years.

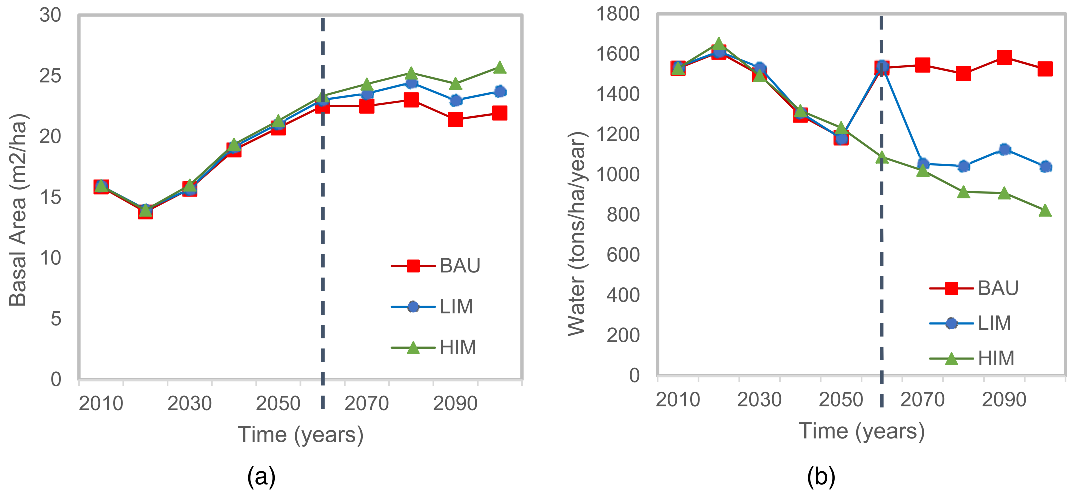

Fig. 6. Temporal evolution of basal area (left) and ground/runoff water production (right) over time.

planning horizon. The increase in volume and volume increment is driven by numerous factors, including: a shift in age class structure towards older stands (Fig. 5), an increase in area (Fig. 4) being afforested with the high productive Red pine, Anatolian pine and Cedar replacing degraded stands; an increase in the productivity of stands as they reach productive stages; and regenerated stands growing according to the empirical yield curve curves. This trend is consistent with national projected forest C stock trends, where forests are expected to change from a net sink of 2.2 Tg C/yr. to a net gain of 6.8 Mt Tg C/yr. (Tolunay, 2011). It is expected that the C sequestration of Turkish forests is largely influenced by the increase of forest area and their productivity over the last three decades as a result of a shift towards a more sustainable forest management philosophy (Baskent et al., 2008).

It is interesting that the forest C stock change values stabilize after 2080 and almost remain C neutral up to 2100. This is more apparent in LIM and HIM scenarios (Fig. 7). This is probably related to the stabilization of the volume increment for the period 2080 to 2100, again consistent with a shift in age class distribution to older more productive stands.

Forest biomass C pools constantly increases from 18 tC/ha to 35 tC/ha even 45 tC/ha by 2100 for all scenarios (Fig. 8). The consistent increase is more prevailing in HIM scenario than expected. Above ground living biomass represents up to nearly 75% of the total forest C stock. (Fig. 8).

The slight increase in HWP removals (i.e., stock in products, Fig. 7) from −0.2 to 0 tC/ha/yr. between 2010 and 2100 for all scenarios appears to be driven again by an increase in the harvest and a sporadic slight decrease in allocation of long life saw logs to the sawn wood HWP pool (Figs. 9 and 10). It is apparent that more harvest is derived from thinning after 2060, as indicated by the larger proportion of pulpwood (representing industrial mix use of wood) and remaining logs in harvest after 2040. This is quite obvious in HIM scenario as intensive management actions (thinning) are prescribed.

There are varying yet small differences in the C sequestration trends for forest products, HWP and energy substitution across the three different scenarios (Figs. 7, 11 and 12). Total C balance is a hard to compare visually between the scenarios (Fig. 7). However, the total long-term C sequestration rate (average over the whole simulation time span, (broken blue line in Fig. 7) is higher for the HIM scenario. This is due to: a) the lower degree of energetic wood use in the LIM and HIM scenarios (Figs. 9 and 12); b) a lower allocation of pulpwood and sawn wood to the HWP pool and product substitution in the BAU scenario (Fig. 11) and c) a slightly lower forest C stock change in the scenario (Fig. 7).

The differences in the forest C stock changes (Fig. 7) appear to be related to a slightly lower harvest for the LIM and HIM scenario, when compared to the BAU scenario and the smaller increase in volume increment for the LIM and HIM scenarios, compared to the BAU scenario. The possible reason for these differences in volume increment can be attributed to the fact that there is a higher replacement rate of less productive areas with highly productive Red pine, Anatolian pine and Cedar, attributable to the higher rate of afforestation in LIM and HIM scenarios. There is an increased allocation of harvested wood for bioenergy under the LIM and HIM scenarios and a higher energy production and emission avoidance by fossil fuel replacement (Fig. 12). This may result in a higher C removal when compared to the BAU scenario (Fig. 7).

4. Discussions

This paper focused on the effects of three different management scenarios on some ecosystem services like C sequestration, water provision, habitat for biodiversity and timber production using a multiple use forest management planning approach. First of all, it provided information about the use and the performance of a DSS in integrating ecosystem services into the planning process. Furthermore, current developments and future challenges are recognized in accommodating important ES into management planning process with different

Table 3
Chemical conditions in the forested areas for the 3 scenarios. Evolution of the indicators over time, on a scale from 1 (low) to 7 (high).

Time	Harvested areas			Rotation length			Applied chemicals			Average		
	BAU	LIM	HIM	BAU	LIM	HIM	BAU	LIM	HIM	BAU	LIM	HIM
2000–2020	4	5	5	5	5	5	7	7	7	5.33	5.67	5.67
2020–2040	5	5	6	5	5	5	7	7	7	5.67	5.67	6.00
2040–2060	5	5	6	5	5	5	7	7	7	5.67	5.67	6.00
2060–2080	5	6	6	5	5	5	7	7	7	5.67	6.00	6.00
2080–2100	5	6	6	5	5	5	7	7	7	5.67	6.00	6.00

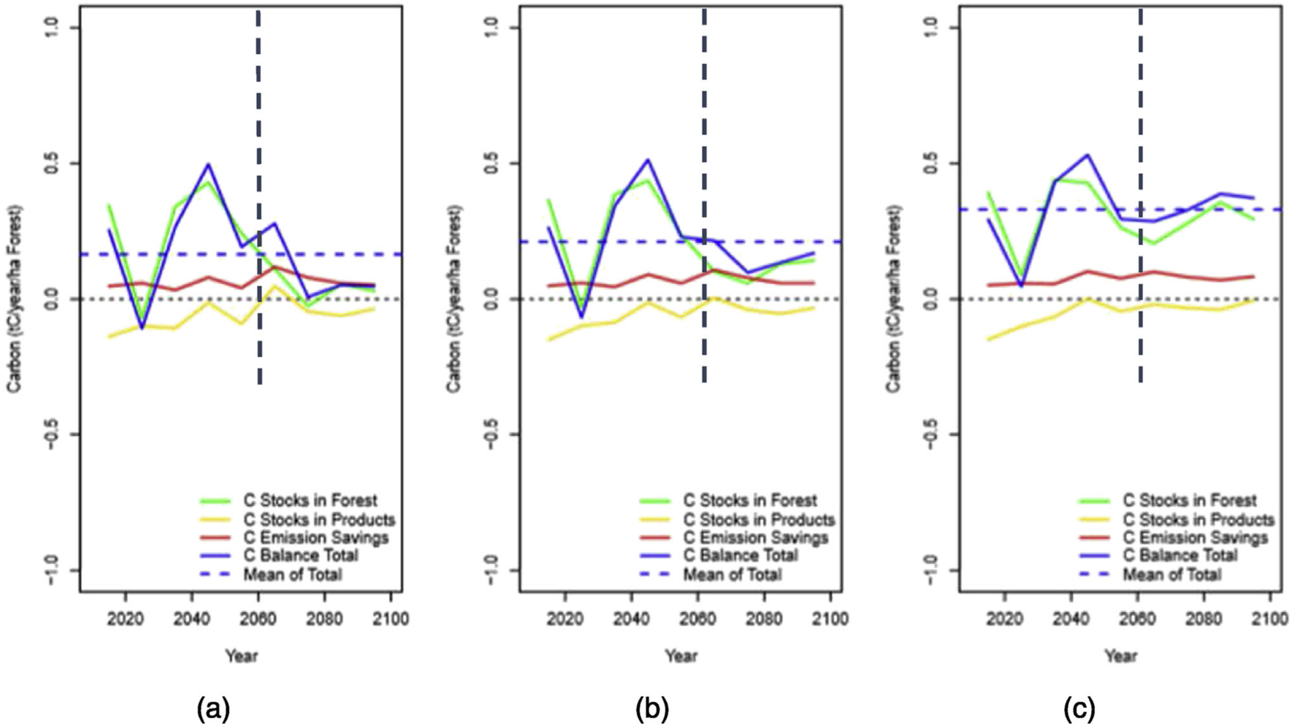

Fig. 7. Total carbon balance of forest, HWP and emission savings (energy substitution) for BAU scenario (left), LIM scenario (middle) and HIM scenario (right) over 100 years.

management strategies under in effect management guidelines and policies in a real case study area.

The dynamics of the forest landscape over time could be seen as beneficial to biodiversity as they overlap with the stated goals for key habitat structures, subject to the commitment to and fulfillment of the required spatial configuration of forest structure. The forest management and silvicultural guidelines strongly state that individual tree species and understory vegetation be protected during all forest management activities, small forest openings be left intact for wildlife, the natural composition of forest stands be saved and key habitats/species be protected to circumvent any concern for biodiversity conservation (Anonymous, 2008; Barbier et al., 2008).

Although the three scenario projections generate outcomes that may not be compatible with some of the biodiversity requirements (i.e.,

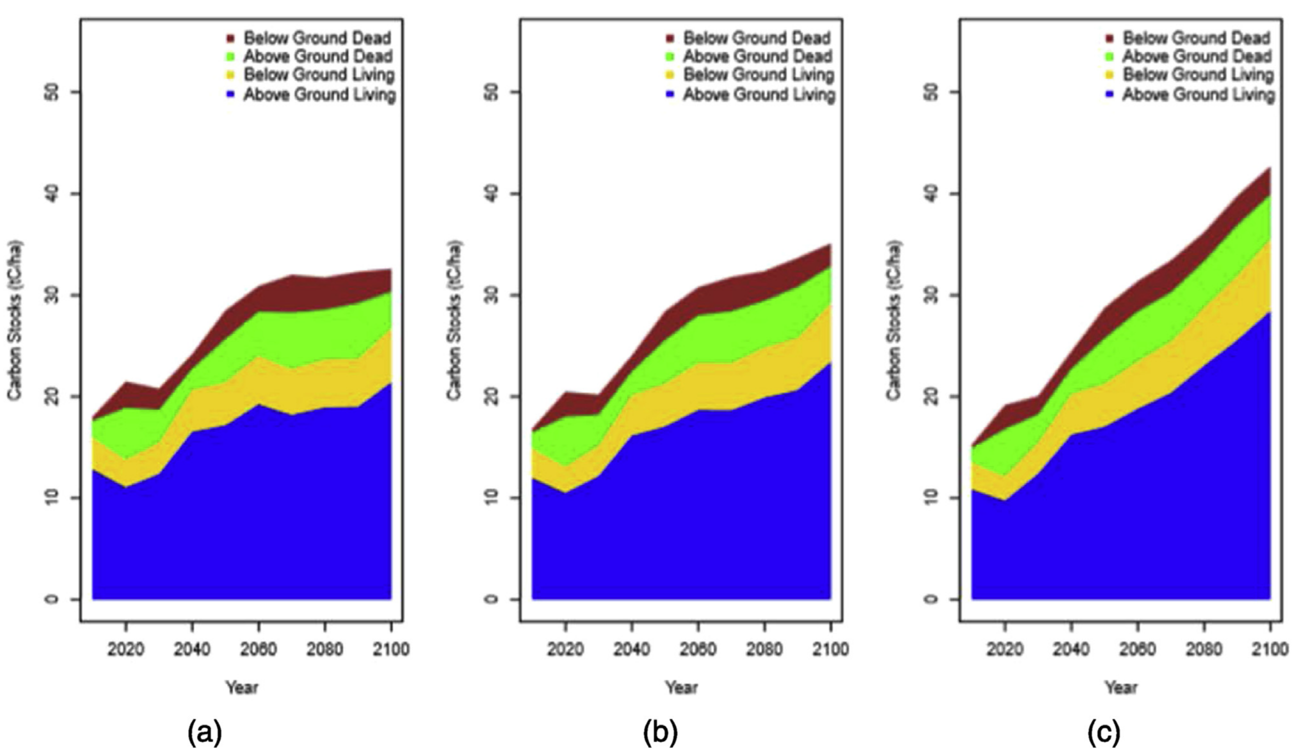

Fig. 8. Forest C stocks in living and deadwood biomass for BAU scenario (left), LIM scenario (middle) and HIM scenario (right) over 100 years.

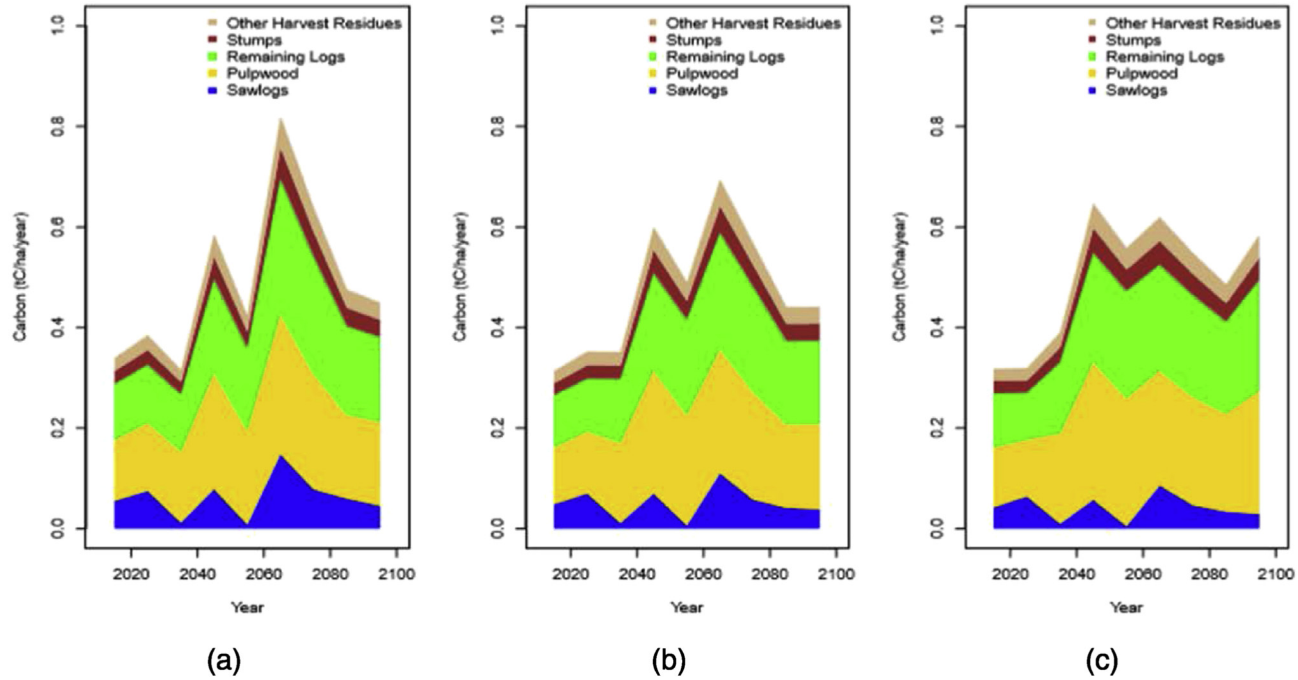

Fig. 9. Harvested C pools for BAU scenario (left), LIM scenario (middle) and HIM scenario (right) over 100 years.

declining larger trees, junipers and deadwood), the current natural tree composition is kept intact and ground implementation follows biodiversity conservation requirements to a certain extent. The crucial caveat regarding these conclusions is, however, that it is currently difficult and challenging for these outcomes to be accepted by stakeholders. Can the climate change effect to the forest growth be reflected and realized, the appropriate spatial layout of the forest management actions be developed and followed and finally the appropriate forest classification be in place? The important concern is that, aside from the coarse biodiversity goals, it is important to find out the finer biodiversity concerns in the sample area (such as target species, sensitive habitats) in order to specifically develop management strategies to generate the appropriate forest conditions and configurations with a DSS.

In terms of carbon sequestration, observed increase in the total forest sink for forest in the Pozantı FPU appears to be related to age class shifts, increasing afforestation areas and an increase in forest productivity overtime. This is consistent with national GHG projections for managed forest in Turkey (Tolunay, 2011) and the findings by Böttcher et al. (2008). Additionally, the long-term C balance for the areas seems to be a small net emission. The marginal differences in the total C balance across the management scenarios are related to a

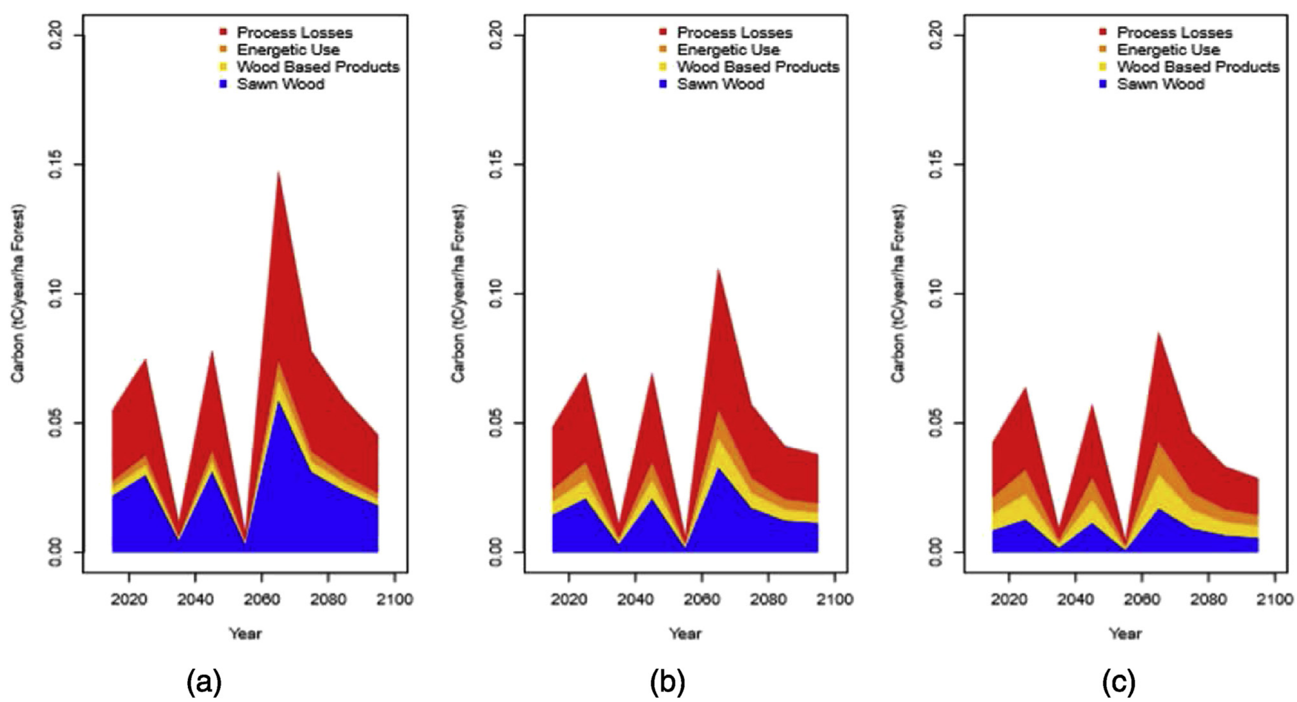

Fig. 10. Allocation of sawlog into the wood products pool for BAU scenario (left), LIM scenario (middle) and HIM scenario (right) over 100 years.

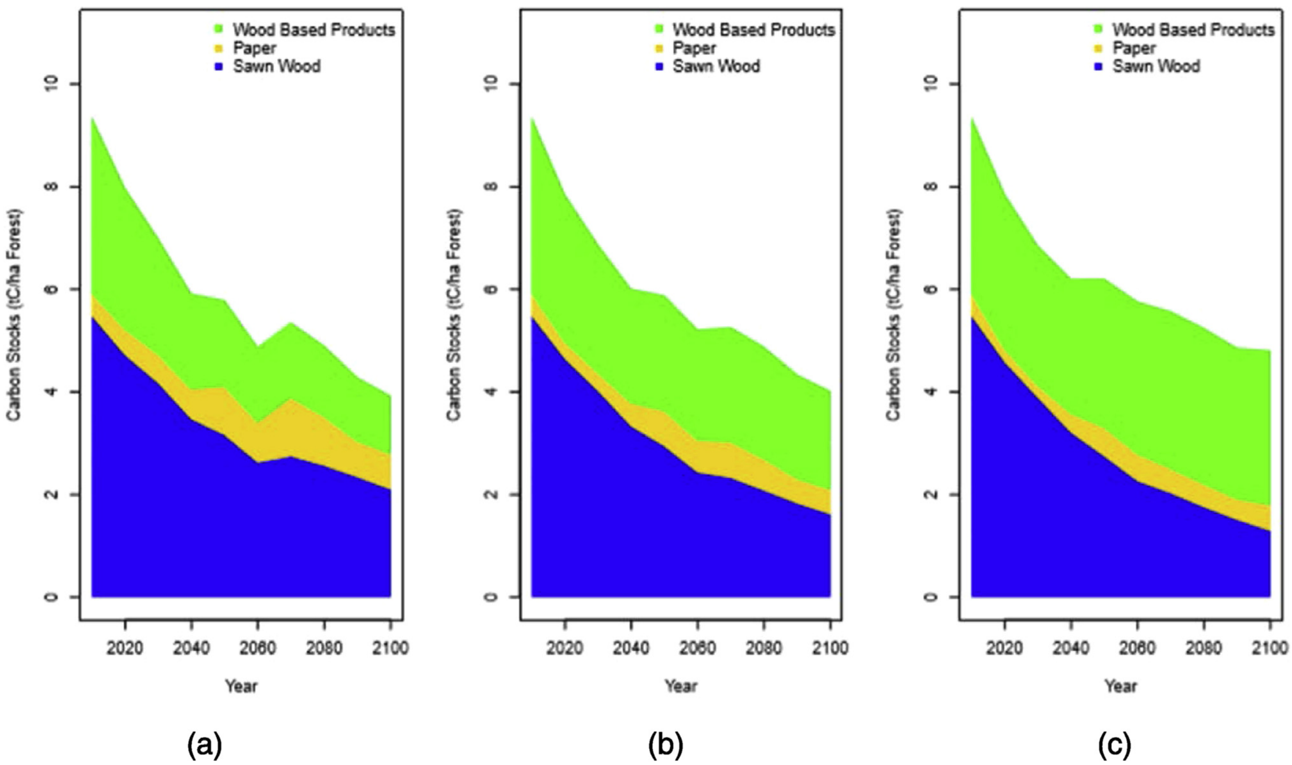

Fig. 11. HWP C stocks for BAU scenario (left), LIM scenario (middle) and HIM scenario (right) over 100 years.

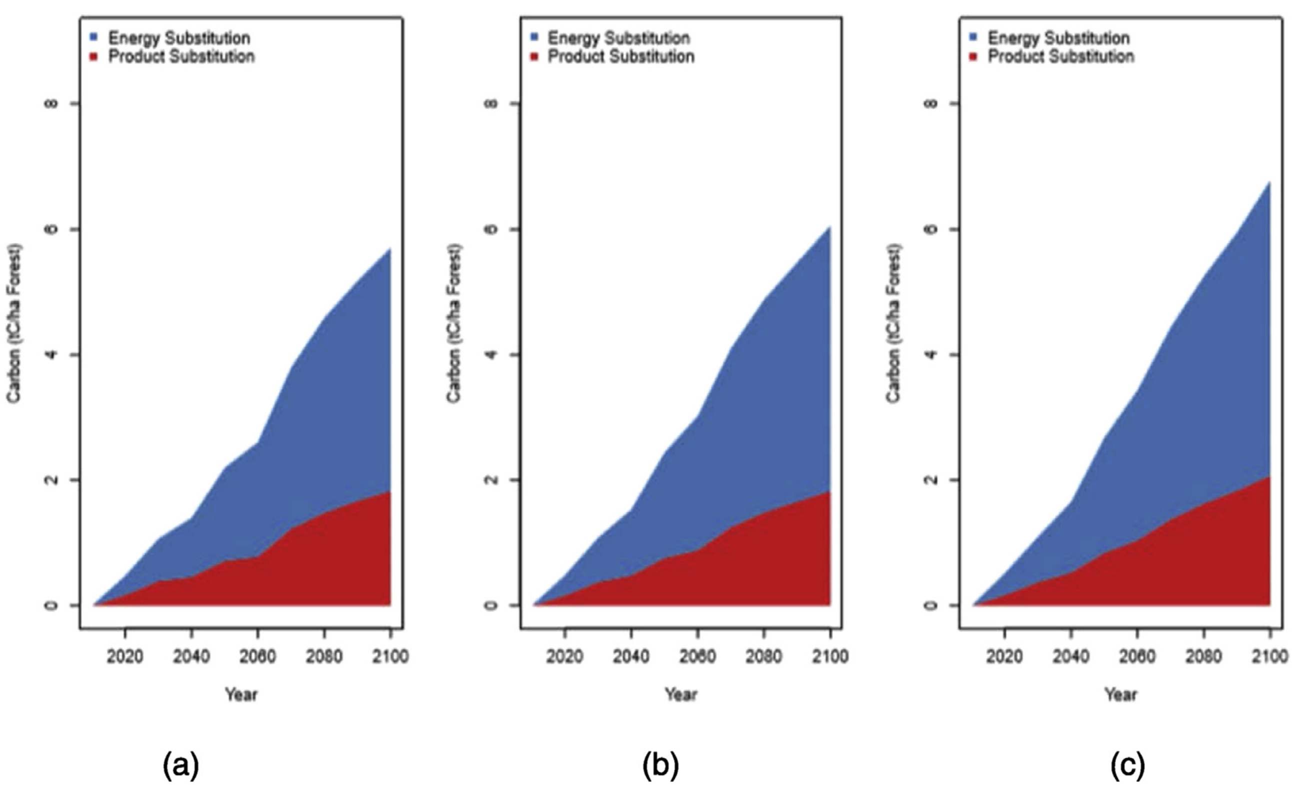

Fig. 12. Cumulative emission saving from energy and product substitution BAU scenario (left), LIM scenario (middle) and HIM scenario (right) over 100 years. Exploring the effects of climate change mitigation scenarios on timber, water, biodiversity and carbon values: A case study in Pozanti Planning Unit, Turkey.

smaller increase in volume increment in the BAU scenario (higher in other scenarios) and a higher allocation of harvest to energy production for the LIM and HIM scenarios. Allocation of harvested products into long term HWP pools appears to result in a higher sequestration potential, when compared to wood use for bioenergy.

Although water production was not taken as a specific forest management objective as in an optimization based DSS, soil and water protection processes are always, by default, relevant. Various forest use

areas as management units are classified specifically to accommodate water management objectives. Thus, such a management planning concept provides opportunities to maintain the related forest objectives. Specifically, the projection of future forest developments with three planning scenarios allows better production of water runoffs and soil protection over time. There are some slight differences among output of management scenarios; LIM and HIM scenarios create better forest conditions to protect soils against erosion yet produce less amount of runoff water over time compared to the BAU scenario.

Water quality was not projected specifically with the DSS to supply fresh water needs of people. The current projection of forest developments indicates that the outputs of the LIM and HIM scenarios are able to provide better opportunities for the production of fresh water compared to the other scenarios due to high turnover rate of forest openings with afforestation activities and the replacement of current underproductive stands with more productive future/regenerated stands. This is a rather qualitative assessment and there needs a more quantitative assessment of fresh water dynamics over time with the modeling approach to forecast the future forest conditions with respect to water quality. In the mean time since the dominant tree species is Calabrian pine, there is almost always a fire threat in the area that would jeopardize the potential supply of various forest values. One important concern is the protection of riparian buffers to preserve water quality. The current forest management guidelines insist on the provision of riparian buffers around all season streams, lakes and wetlands to safeguard the wildlife habitat and contribute to increase water quality. Rotation lengths are long enough, particularly in management units identified for other than wood production objectives. However, the forest road network poses a risk to the production of fresh water. That remains a challenge future study. Another potential risk is the increasing use of ecotourism and recreational activities in the designated areas. The relevant measures are to be taken into account to control the level of recreational activities.

It is interesting to see that Fig. 1 through 7 are quite consistent and persistent and that the decade 2050–2060 (the dashed lines) is the period of inversion in the behavior of three scenarios. This cannot be much of a coincidence. However, it could rather be the effects of "gradual afforestation" of bare lands/degraded areas taken its effect after a rotation period. Most of the areas are afforested with *Pinus brutia* whose rotation period is 60 years –they have effects after a rotation period. Furthermore, all regenerated stands develop according to the empirical yield tables whose values are greater than the current yield values –the current stands are underproductive. Thus, those two parameters may cause the inversion of the scenarios approximately in the period of 2060–70. Aside from these parameters, that might be other causes that are quite difficult to comment on.

Very few studies particularly pinpoint the effects of climate change on long term forest development and planning. For example, Bredemeier (2011) states that careful planning of management is essential wherever tradeoff situations between forest growth and water yield emerge. In Boreal forests of Canada, Daniel et al. (2017) incorporated climate uncertainties in forest management planning and concluded that management strategies aimed at reducing the future level of timber harvest offer an opportunity to mitigate the climate change risks. Importantly, Albrich et al. (2018) showed that achieving maximum level of forest values at the expense of temporal instability of ES supply is not realistic; suggesting diverse management strategies fostering large spectrum of opportunities with silvicultural measures reducing risks and providing stable ecosystem services. In Wales, Ray et al. (2015) showed that current management practices are unable to deliver the expected ecosystem services such as timber, biodiversity and the carbon sequestration under the warmest and driest climate scenarios. They stated that unless some adaptation measures to climatic impacts (i.e., diverse species forests with low-impact silviculture system) are considered nearly 20–50% chance of failing to deliver on some of the ES. Albert et al. (2016) examined the effects of climatic uncertainty on forest management in the north German lowlands. As expected, initial conditions of site and climate characteristics, age class distribution and species proportions heavily influenced the projected forest development (i.e., standing and harvested volume and increment). To a much stronger degree, the silvicultural measures are capable of controlling forest development over time. While they recommend that responsible forest management planning with a flexible formulation of adaptation strategies in climate change research is necessary, the climate change effects on ecosystem services were not directly evaluated to compare to the results of our study. Besides, quantifying as well as assessing the consequences of climate change on the provision of various ecosystem services has been an undergoing and demanding research challenge due to the large knowledge gaps (Polce et al., 2016).

However, some limitations need to highlighted. The simulation based DSS used is deterministic, disregarding the inclusion of biological and economic risks involved –stochastic modeling is necessary. The DSS used is an aspatial model excluding the effects of spatial parameters such as size, shape and juxtaposition of management activities and patches. Most striking issues is the presumption of climate change effects on forest growth. The derived assumptions are established for the region based on a linkage to a study in a similar region in Portugal. In fact, simulation studies should consider deploying a plausible range of climate change effects under the various emission pathways for a given region. Thus, the resultant predictions from the assessment should be cautiously interpreted within the context of the specific outcomes for the scenarios considered, the degree of uncertainty that is associated with the results, inferences and overall conclusions. In fact, spatial forest planning is a logical forest modeling approach that accommodates spatial requirements as well as multiple, often conflicting management objectives. Additionally, the missing carbon pools such as carbon storage in soil and recycling of products need to be included in the model. The forest biomass is principally calculated based on the growing stock of two categories as coniferous and broadleaf species. In reality, a species based biomass model needs to be developed and used for more accurate calculation of carbon stocks. Besides basal area, other stand parameters such as number of trees, leaf area, crown closure and stand density may need to be used in estimating water resource value since the quantity and quality of water produced depends on the quantity and the structure of the forest ecosystem.

5. Conclusions

Three distinctive forest planning scenarios were developed and implemented in a typical case study area to reflect forest dynamics under different management interventions focusing on climate mitigation issues. The forest was projected with a simulation based model in compliance with the current forest management guidelines. While all requirements were not included in the scenarios, various other/national planning parameters were used to abide by the general framework of the climate change scenarios. Based on the results of the projections and the discussions some apparent conclusions are highlighted below:

- The prevailing variable seems to be the areas of afforestation. The afforestation target for each scenario was met to a higher extent and thus the total forest area increased over time due to the periodic gradual inclusion of "bare forest lands" into the productive forest areas through afforestation activities.
- The standing volume, basal area as well as the volume increment per ha per year increased significantly and gradually from BAU scenario to LIM and to HIM scenarios over time, as degraded areas were either afforested or regenerated becoming more productive forest areas over time. Also bare forest lands contributed additionally to the gradual increase of growing stock over time depending on the level of afforestation.
- The share of broadleaved species decreased over time gradually

from the BAU scenario to LIM and to the HIM scenarios due to the afforestation of bare lands with softwood trees.

- No obvious trend of changes in harvesting level as well as in standing volume per size class was observed over time in the scenarios.
- The sawlog volume per ha seemingly decreased and other wood assortment increased over time as smaller material was harvested

Finally, we note that the rate and intensity of forest management interventions greatly impacts on the provisioning level of ecosystem services. The management scenarios allowed better control of water runoffs and beneficial to biodiversity conservation. The management scenarios with intensive treatment actions provided better opportunities for fresh water production. The increase in the total forest sink for carbon storage is related to the level of productive forests, the rate of afforesting bare lands and degraded areas, and age class shifts towards older stages. Climate change phenomenon may be better managed with a dynamic climate change model and a careful design of management scenarios in forest management planning.

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